NASA SP-5037

TECHNOLOGY
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Technology Utilization Division

# Bibliography on

# SOLID LUBRICANTS

## WITH INDEXES




NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA SP-5037

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# Bibliography on SOLID LUBRICANTS

**WITH INDEXES**

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. February 1966

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# FOREWORD

The Administrator of the National Aeronautics and Space Administration has established a technology utilization program for "the rapid dissemination of information. . . .on technological developments. . . .which appear to be useful for general industrial application." From a variety of sources, including NASA Research Centers and NASA contractors, space-related technology is collected and screened; and that which has potential industrial use is made generally available. Information from the nation's space program is thus made available to American industry, including the latest developments in materials, management systems, processes, products, techniques and analytical and design procedures.

This publication is a part of a series of bibliographic publications intended to serve both scientific and technical personnel and the libraries and librarians who support them.

THE DIRECTOR, *Technology Utilization Division*
*National Aeronautics and Space Administration*

# INTRODUCTION

This bibliography is designed to assess and identify the current literature on the applications and uses of solid lubricants.

The purpose of this series of publications is to provide industry with summarizing information on innovations contained in NASA and other space technology literature.

The bibliographies are intended to indicate the wealth of new information and new technology available from the collections of the National Aeronautics and Space Administration. It is the purpose of the Technology Utilization Bibliographies to select and list available information of special interest to the industrial user.

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Abbreviations that frequently appear in the citations describing the references are listed below:

| Abbreviation | Full Meaning |
|---|---|
| CFSTI | Clearinghouse for Federal Scientific and Technical Information |
| OTS | Office of Technical Services |
| ph | Photostat. Full size copies of the document are available in photostatic form |
| mi | Microfiche. Copies of the document are available in microfilm form |
| MF | Microfiche. See mi |
| HC | Hardcopy. See ph |

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## TPA ENTRIES

**N62-10009** National Aeronautics and Space Administration. Lewis Research Center, Cleveland.

**LUBRICATING PROPERTIES OF CERAMIC-BONDED CALCIUM FLUORIDE COATINGS ON NICKEL-BASE ALLOYS FROM 75° TO 1900° F.**

Harold E. Sliney. Feb. 1962, 39 p. 13 refs. (NASA TN D-1190) OTS, $1.00

Ceramic-bonded calcium fluoride coatings lubricated a vacuum-melted, nickel-base alloy (René 41) at temperatures up to 1900° F. An air-melted, nickel-base alloy (Inconel X) was effectively lubricated to 1500° F. The wear life of the coating on the air-melted alloy was good from 500° to 1500° F; on the vacuum-melted alloy, life was good from 500° to 1700° F and then fair up to 1900° F. The most favorable friction properties were obtained at high ambient temperature and high sliding velocity. Coatings applied to slightly preoxidized Inconel X or René 41 were more uniform in appearance and had better endurance life than coatings applied to the unoxidized metals.

**N62-11695** Midwest Research Inst., Kansas City, Mo.

**LUBRICATION STUDIES WITH LAMELLAR SOLIDS.**

**Final Report, June 1, 1961 to Dec. 31, 1961.**

Paul Bryant. Wright-Patterson AFB, Ohio, Directorate of Materials and Processes, Jan. 1962. iv, 23 p. 18 refs.

(ASD-TDR-62-55) (Contract AF 33(616)-7823; Proj. 7022)

A basic research program is being conducted to determine the mechanisms of friction and wear for lamellar solid lubricants. Single crystals of graphite were grown and an UHV ($2 \times 10^{-13}$ Torr) controlled atmosphere system was perfected. A stress-etch mechanism is proposed here to explain the effect of atmospheric gases upon the lubrication properties of lamellar solids. The proposed mechanism describes the observed reduction of cohesive energy (mica was 30 times stronger in vacuum than in air) by an external attack upon the bifurcation line or shearing edge; the mechanism thus depends on the well-established processes of surface adsorption and migration without requiring diffusion of air molecules between lamellae. (Author Abstract)

**N62-11821** Directorate of Materials and Processes, Aeronautical Systems Div., Wright-Patterson AFB, Ohio.

**DEVELOPMENT OF OPTIMUM METHODS FOR THE PRIMARY WORKING OF REFRACTORY METALS.**

**Interim Report, June 1, 1961 to July 31, 1961.**

P. S. Duletsky and V. DePierre. Jan. 1962. 32 p. 2 refs.

(WADD-TR-60-418, Part III) (ASD Proj. 7351)

Improved lubrication techniques using Corning 7900 glass mixture were developed for extruding refractory metals at 4000° F. The suitability of zirconium oxide ceramic-coated steel dies for extrusion at 4000° F was confirmed. Improved extrusion facilities at WPAFB give reproducible, good quality, round and rectangular bar extrusions at temperatures up to 4000° F and reduction ratios of 9.5 to 1. (Author Abstract)

**N62-12330** National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.

**HEARINGS FOR VACUUM OPERATION RETAINER MATERIAL AND DESIGN.**

Harold E. Evans and Thomas W. Flatley. Washington, NASA, May 1962. 20 p. refs.

(NASA TN D-1339)

OTS: $0.50.

Fully machined retainers of five different materials, with all balls and races of gold-plated 440C stainless steel, were tested. Both pure gold plating and gold with additives were investigated. Size R2-5 bearings were run without external loading at a nominal motor speed of 10,000 rpm and the goal is a bearing life of 1,000 hours in an ambient pressure of $10^{-7}$ torr. The results show that: (1) thin metallic films as lubricants show real promise when used in a vacuum environment; (2) pure gold plating is not as effective as the plating with additives; (3) fully machined retainers provide good performance, and the use of relatively hard retainer materials significantly extends the useful life of the bearings; and (4) the bearing failures tended to be catastrophic rather than gradual, making the prediction of the onset of failure difficult. A special multiport oil-free vacuum system designed and built for this program proved extremely effective in achieving a vacuum of $10^{-7}$ torr and in permitting the operation of seven individual tests at one time. (Author Abstract)

**N62-12423** Midwest Research Inst., Kansas City, Mo.

**LUBRICATION BEHAVIOR AND CHEMICAL DEGRADATION CHARACTERISTICS OF EXPERIMENTAL HIGH TEMPERATURE FLUIDS AND LUBRICANTS.**

**[Final Report, Jan. 1961 to Dec. 1961.]**

Vernice Hopkins, Andrew D. St. John, and Donnell Wilson. Wright-Patterson AFB, Ohio, Directorate of Materials and Processes, Mar. 1962. 116 p. 7 refs.

(WADD-TR-60-855, Pt. II) (Contract AF 33(616)-6854; Proj. 3044)

MLO 60-294 resisted degradation from high shear stresses at 400°, 500°, 550°, and 600° F and wear of the hydraulic pump was small through 500° F. MLO 59-91 at 400° F permitted rapid wear in the hydraulic pump. MLO 59-692 was not degradated by high shear stresses at 550° and 700° F. QF-258 was not degradated at 550° F but experienced a drop in viscosity and flash point during a 100 hr. shear stability experiment at 700° F. Bulk modulus data are presented for MLO 60-294 and QF-258. Results of lubricant behavior in a rolling-sliding contact are presented, and a partial analysis of roller-cage

stability is given. Development of the high pressure viscometer is discussed. Solid film lubrication of spherical bushings and the effects of thermal aging of a film are presented. Extreme pressure lubrication of M-10 tool steel at 400° and 600° F and of 52100 steel at 275° and 400° F with an ester of TMP with various additives is discussed. (Author Abstract)

**N62-12809** Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena.
**BEHAVIOR OF MATERIALS IN SPACE ENVIRONMENTS.**
L. D. Jaffe and J. B. Rittenhouse. Nov. 1, 1961. 124 p. 330 refs.
(NASA Contract NASw-6)
(JPL-TR-32-150)

In the vacuum of space, magnesium sublimes appreciably at elevated service temperatures; zinc and cadmium sublime at ordinary temperatures. Among the organics, polysulfides, cellulosics, acrylics, polyvinyl chloride, neoprene, and some nylons, polyesters, epoxys, polyurethanes, and alkyds, break down at rather low temperatures in vacuum. Polyethylene, polypropylene, most fluorocarbons, and silicone resins do not decompose significantly in vacuum below 250° C. Except for plasticized materials, significant loss of engineering properties in vacuum is unlikely without appreciable accompanying sublimation or decomposition. Also, escape of gases through walls which are gas-tight at 1 atmosphere will not be of concern. Certain low vapor pressure oils and greases, tetrafluoroethylene, and thin films of $MoS_2$, Au, and Ag can probably provide adequate lubrication when suitably selected for the speeds, loads, and times of service.

The particles of the Earth's radiation belts will cause radiation damage to organics and to optical properties of inorganic insulators. Semiconductors will be damaged in the inner belt; their more sensitive properties will also be affected by solar flare emissions. Exposed surfaces of most materials may be damaged by the radiation belts and perhaps by solar charged particle emissions. Optical properties of exposed polymers and ceramics will also be affected by solar ultraviolet and X-rays. Sputtering away of material by collision with ions or atoms in space is probably negligible. Erosion by meteoroids is significant only close to the Earth. The probability of penetration by meteoroids falls sharply with increasing distance from Earth. Much more frequent than penetration is spalling of fragments from the inside of walls struck by meteoroids. The efficiency of walls in preventing penetration and spalling can be increased by splitting the walls into a thin front plate and a thicker main plate; quantitative bases for the design of such spaced armor are presented. (Author Abstract)

**N62-13501** Rocketdyne, Canoga Park, Calif.
**H-1 LUBRICATION STUDIES. [Covering Period 1 Nov. 1960 to 1 Mar. 1962.]**
O. I. Thorsen. Mar. 1, 1962. 127 p. 55 refs.
(NASA Letter Contract NAS7-3; G. O. 5868)
(Rept. R-3451) OTS: $10.10 ph, $4.01 mf.

This report presents the results of various lubrication studies to pretreat gear surfaces with extreme pressure (EP) additives, platings, and coatings so that these gear surfaces function properly when later lubricated in RP-1 (kerosene) only. A total of 32 additives and 16 platings and coatings were tested in the Falex tester and a WADD (Ryder type) gear tester. The results of these tests and recommendations are reported. Included is a review of the effort necessary to make the WADD gear tester operate at a high speed (20,000 rpm) and high load (4000 + lb per in. of gear face). (Author Abstract)

**N62-13625** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
**FRICTION, WEAR, AND EVAPORATION RATES OF VARIOUS MATERIALS IN VACUUM TO $10^{-7}$ mm Hg.**
Donald H. Buckley, Max Swikert, and Robert L. Johnson. Repr. from ASLE Trans., v. 5, 1962. p. 8-23. 38 refs. Presented at the ASLE Lubrication Conf., Chicago, Ill., Oct. 1961.

Evaporation data on soft metals, lubricating inorganic compounds, and various reference materials are reported for temperatures from 75° to 1000° F in vacuum as low as $10^{-7}$ mm Hg. Observations on modes of vacuum degradation (e.g., evaporation or dissociation) and methods of experimentation are related. Friction and wear data are presented for several unlubricated metals (e.g., type 440-C steel) and metals coated with inorganic (e.g., $MoS_2$, $CaF_2$), as well as with soft metal films in vacuum at ambient pressures between $10^{-6}$ and $10^{-7}$ mm Hg. (Author Abstract)

**N62-13875** Directorate of Materials and Processes, Aeronautical Systems Div., Wright-Patterson AFB, Ohio.
**A STATISTICAL ANALYSIS OF THE FRICTIONAL PERFORMANCE OF SOLID FILM LUBRICANTS. PART II—CERAMIC BONDED FILM IN AIR. Technical Documentary Report [May 1960 to May 1961.]**
Martin R. Adams and Mary D. Lum. March 1962. 45 p. 10 refs.
(WADD-TR-61-49, Pt. II)

This report presents a statistical analysis of the performance of a ceramic bonded solid film lubricant. The ceramic bonded film, $PbS/B_2O_3$ (in a six to one weight ratio of lubricant to binder), was developed by the Midwest Research Institute under contract with the Air Force and is of interest in the 700 to 1000° F temperature range. Experiments were conducted on the Hohman A-6 tester with two loading shoes. The analysis of variance shows that, within the range of the variables studied, the main effects of bearing load and ambient temperature are significant and that a response to a change in temperature depends on speed.

The results are analyzed with an approximate and with an exact statistical method. The two methods lead to identical conclusions. (Author Abstract)

**N62-14005** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.
**EVALUATION OF BALL-BEARING PERFORMANCE IN LIQUID HYDROGEN AT DN VALUES TO 1.6 MILLION.**
Herbert W. Scibbe and William J. Anderson. Repr. from ASLE Trans., v. 5, 1962. p. 220-232. 7 refs.

Experimental data were obtained in liquid hydrogen (-423° F) on two series of 40-mm-bore ball bearings utilizing various retainer materials. Effects of diametral clearance and retainer material on limiting DN value (product of bearing bore in mm and shaft speed in rpm) were investigated at thrust loads to 500 lb and at speeds to 41,200 rpm. An analysis was made to determine the effect of ball size and race curvatures on the heat generated in bearings of both series as a result of ball spin. The results, supported experimentally, indicate that higher limiting DN values at a specific thrust load could be obtained with an extremely light series (1908) bearing with open-race curvatures than with a light series (108) bearing. Successful operation to a DN value of 1.6 million was obtained with 1908 bearings (at 110 lb thrust load) using two different retainer materials. The glass-fiber-filled PTFE (polytetrafluoroethylene) retainer exhibited much less wear than the $MoS_2$-filled phenolic retainer at these test conditions. (Author Abstract)

**N62-14363** Illinois U., Urbana.
**SOLID FILM LUBRICANT-BINDER PHENOMENA: $PbS-B_2-O_3$ SYSTEM. [Final] Technical Documentary Report [Apr. 1, 1961 to Mar. 31, 1962].**
H. R. Thornton, Doris M. Krumwiede, J. F. Benzel, R. J. Forlano, and Dwight G. Bennett. Wright-Patterson AFB, Ohio, Directorate of Materials and Processes, May 1962. 46 p. 6 refs.
(Contract AF 33(616)-7978)
(ASD-TDR-62-449, Pt. I)

The basic techniques, X-ray diffraction, microscopy, and fusion studies, along with the supplementary techniques of differential thermal analyses and friction and wear measurements, are described

as related to the PbS-$B_2O_3$ system. Data indicated that PbS and $B_2O_3$ were the only crystalline phases expected in the majority of the specimens. A glassy phase exists between 300° and 1500° F. The lubrication mechanism in the high $B_2O_3$-low PbS mixtures is a function of the liquid phase present, while the liquid phase only affects the low $B_2O_3$-high PbS mixtures above 980° F. Frictional compatibility is necessary between the lubricating pigment and binder over the entire temperature range. (Author Abstract)

**N62-14392** Directorate of Materials and Processes, Aeronautical Systems Div., Wright-Patterson, AFB, Ohio.

**PROCEEDINGS OF THE AIR FORCE-NAVY-INDUSTRY PROPULSION SYSTEMS LUBRICANTS CONFERENCE [HELD IN SAN ANTONIO, TEXAS ON NOV. 15-17, 1960. Final] Technical Documentary Report.**

G. A. Beane IV and K. L. Berkey. May 1962. 237 p. 72 refs.
(Co-sponsored by Southwest Research Inst. under Contract AF 33 (616)-7223)
(ASD-TDR-62-465)

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22. LIQUID-MERCURY LUBRICATED HYDROSPHERE BEARINGS. G. Y. Ono and D. C. Reemsnyder. p. 227-239. 4 refs.

**N62-16761** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio.

**CERAMIC SURFACE FILMS FOR LUBRICATION AT TEMPERATURES TO 2000° F.**

R. L. Johnson and H. E. Sliney. Repr. from Am. Ceram. Soc. Bull., 41, no. 8, Aug. 15, 1962. p. 504-508. refs.

The introduction of some oxides, sulfides, and halides at the interface between sliding metal surfaces decreases the adhesive forces between them and thereby often reduces the friction coefficient; galling and metal transfer are reduced or eliminated and low wear rates often result. Data are presented on NASA investigations of the lubricating properties of selected inorganic compounds as powders, naturally formed scales on metals, and as components of ceramic coatings. Coatings which have shown considerable promise are lead monoxide bonded to stainless steels with lead silicate (good to 1250° F) and calcium fluoride coatings bonded to nickel-base alloys with a cobalt oxide, barium oxide, boric oxide binder (good to 1900° F). (Author Abstract)

**N62-17471** Rock Island Arsenal Lab., Ill.

**THE EFFECT OF VAPOR DEGREASING ON WEAR LIFE AND SALT SPRAY LIFE OF RESIN-BONDED SOLID FILM LUBRICANTS Technical Report**

G. P. Murphy and F. S. Meade Feb. 20, 1962 19 p 2 refs
(RIA-62-652) OTS: $0.50

Two resin-bonded, solid film lubricants were applied to anodized aluminum and zinc-phosphatized, steel-test specimens. One portion of the coated specimens was subjected to a ten-minute exposure in a conventional industrial vapor degreaser containing trichloroethylene. A second portion of the coated specimens was subjected to a similar exposure for a sixty-minute period. Some of the degreaser-treated specimens were further exposed for one week in a 20% salt-spray cabinet. The effect of degreasing and combination of degreasing and salt-spray exposure on the wear life of the coatings was determined on a Falex Lubricant Tester. The following conclusions were drawn: (1) Vapor degreasing for periods in excess of ten minutes decreased the salt-spray protection provided by the solid film lubricant. (2) Vapor degreasing for periods up to one hour has no deleterious effect on the wear of solid film lubricants. (3) Vapor degreasing followed by salt-spray exposure has no effect on the wear life of solid film lubricants applied over sealed anodized aluminum. If the anodized film is not sealed, vapor degreasing followed by salt-spray exposure produces a drastic reduction in the wear life. Author

# 1963
# IAA ENTRIES

**A63-11057**

THE USE OF FREE-ENERGY RELATIONSHIPS IN THE SELECTION OF LUBRICANTS FOR HIGH-TEMPERATURE APPLICATIONS.

F. K. Orcutt, H. H. Krause, and C. M. Allen (Battelle Memorial Institute, Columbus, Ohio).

(ASME, Spring Lubrication Conf., Miami Beach, Fla., May 8-10, 1961.)

Wear, vol. 5, Sept.-Oct. 1962, p. 345-362. 10 refs.

Research supported by the USAF, Fairchild Engine and Airplane Corp., and Battelle Development Corp.

Qualitative evaluation of promising lubricants for high-speed ball bearings, operating at temperatures up to 1,200°F. A high-speed rolling disk apparatus is used in the study. The lubricants evaluated are mainly inorganic solids suspended in a gas carrier, and the criteria established and applied in the selection are softness and thermodynamic properties of the lubricants. Thermodynamic calculations are used to judge the probability of chemical reaction between the lubricants and the substrate material. It is found that compounds which are soft and are thermodynamically favorable for chemical reaction with the substrate provide the lowest friction and wear.

**A63-11971**

SLIDING CONTACTS AND FRICTION PHENOMENA IN SPACE.

F. J. Clauss, C. F. O'Hara, S. P. Drake, and F. B. Cooke (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Sunnyvale, Calif.)

(American Society of Metals, Golden Gate Conference, San Francisco, Calif., Feb. 1962.)

IN: Materials Science and Technology for Advanced Applications. Englewood Cliffs, N.J.; Prentice-Hall, Inc., 1962, p. 164-198.

Consideration of the problems anticipated for mechanisms operating in space. Available information is summarized on the applicability of various lubricants and self-lubricating materials to solve such problems as the operation of gears, bearings, and sliding electric contacts. Special emphasis is placed on obtaining long-time reliability under orbital conditions, together with minimum weight and size. The advantages and limitations of various classes of lubricants and self-lubricating materials for spacecraft applications are reviewed, and new data from current experimental studies are presented. Comparisons are made of the lubricating lifetimes provided by several oils and greases on ball bearings operating in air and in vacuum. Graphite, molybdenum disulfide, soft metals, plastics, ceramics, and cermets are among the materials evaluated.

**A63-12681**

MECHANICAL ELEMENTS FOR VACUUM OPERATION.

Harold E. Evans, Thomas W. Flatley, and M. Francis Federline (NASA, Goddard Space Flight Center, Greenbelt, Md.)

American Rocket Society, Annual Meeting, 17th, and Space Flight Exposition, Los Angeles, Calif., Nov. 13-18, 1962, Paper 2711-62. 11 p.

Investigation of the design of mechanical components for aerospace application, with particular reference to bearings and gears. Results of a study of bearings (R2-5 size), operating at 10,000 rpm in a vacuum of $10^{-7}$ mm Hg, indicate that both gold and silver appear promising as lubricants for vacuum operation. The bearings exhibit an early dip in speed, or initial erratic performance, indicating that a run-in period is required. A sudden failure rather than a gradual decrease in speed makes the prediction of impending failure difficult. It is shown that a stainless-steel (303) gear operating with a Delrin gear at a pitch-line velocity of 942 fpm, has run more than 175 hr without failure, in a vacuum of $10^{-7}$ mm Hg. A similar gear, operating with an aluminum gear at a pitch-line velocity of 0.8 fpm, has run for over 700 hr without failure, in a vacuum of $6 \times 10^{-9}$ mm Hg. However, the latter combination, operated at 942 fpm, failed after 1 hr and 54 min.

**A63-16183**

LONG TERM OPERATION AND PRACTICAL LIMITATIONS OF DRY, SELF-LUBRICATED BEARINGS.

D. J. Boes (Westinghouse Research Laboratories, Pittsburgh, Pa.)

Lubrication Engineering, vol. 19, Apr. 1963, p. 137-142.

Description of three series of experiments which demonstrate the ability of a completely dry ball bearing to function satisfactorily for long periods of time under various combinations of load, speed, temperature, and atmospheric environment. This capability is achieved by equipping the standard ball bearing with a ball separator, or cage, that is fabricated from a material possessing inherent lubricating properties. The cage material used is reinforced polytetrafluoroethylene. The bearings operate from $1 \times 10^{-5}$ torr to atmospheric pressure.

**A63-17600**

WEAR AND FRICTION OF MECHANICAL CARBONS IN LIQUID OXYGEN AS INFLUENCED BY TRANSFER FILMS.

W. F. Hady, G. P. Allen, and R. L. Johnson (NASA, Lewis Research Center, Cleveland, Ohio).

American Society of Lubrication Engineers, Annual Meeting, 18th, New York, N.Y., May 1963, Paper 63AM 5B-3. 22 p. 10 refs.

Experimental investigation to determine the lubricating potential and compatibility of mechanical carbons (molded carbon-graphite bodies used as slider materials for seals and bearings) at conditions applicable to lox turbojet operation. Experiments are conducted using a hemispherically tipped rider sliding in a circumferential path on the flat of a rotating disk. Mechanical carbons (either amorphous, graphitic, or a combination of the two) with or without adjuncts, are run submerged in lox against various metal surfaces. The load applied is 1,000 gm, and sliding velocities from 1,000-6,500 ft/min are employed. The results show that dense, highly graphitic carbons have potential use as seal and bearing materials for lox applications. The graphitic carbons with a greater oxidation resistance and a greater capability of forming a transfer film give the lowest wear and friction. Metals that form the most stable oxide films promote greater adherence of the graphite to the mating surface. It is seen that impregnated carbons must be selected with caution because frictional heating generated during sliding can initiate hazardous reactions between oxygen and certain unstable organic compounds.

**A63-24091**

GRAPHITE, MOLYBDENUM DISULFIDE AND PTFE - A COMPARISON.

Arthur J. Stock (Acheson Colloids Co., Port Huron, Mich.).

(American Society of Lubrication Engineers, Annual Meeting, 18th, New York, N.Y., Apr. 30-May 2, 1963.)

Lubrication Engineering, vol. 19, Aug. 1963, p. 333-338; Discussion, p. 338; Author's Closure, p. 338. 45 refs.

Comparison of the properties of graphite, molybdenum disulfide, and PTFE solid lubricants. Complete data presented on load, speed, temperature, and friction show that PTFE has serious limitations; both graphite and molybdenum disulfide can withstand higher loads and greater speeds, and graphite can also withstand higher temperatures.

**A63-25801**

LUBRICATION.

Francis J. Clauss (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Palo Alto, Calif.).

IN: MATERIALS FOR MISSILES AND SPACECRAFT.
Edited by Earl R. Parker.
New York, McGraw-Hill Book Co., Inc., 1963, p. 277-324. 44 refs.

Discussion of lubrication problems in the orbital environment. Silicone oils and greases are among the most successful lubricants tested to date. The tests indicate that they should be suitable for six months of continuous operation in space on small, double-shielded ball bearings in many spacecraft applications, provided that operating temperatures do not exceed 79°C and that speeds do not exceed 8,000 rpm. Thin films of laminar solids, such as $MoS_2$, can provide low running torques, long-wear lives, low evaporation rates, relative insensitivity to temperature, and excellent radiation stability. Plastics, such as Teflon and nylon, offer many advantages as self-lubricating parts for spacecraft mechanisms, among which is a minimum tendency to cold-weld to metals under vacuum conditions. Ceramics and cermets are essentially hard, brittle materials such as sapphire, glass, cemented carbides, fully dense oxides, and Pyroceram. As in the case of plastics, the ceramics and cermets have little tendency to cold-weld to metals under vacuum conditions.

**A63-26050**

MOLYBDENUM-DISULPHIDE - ITS USE IN AIRCRAFT MANUFACTURE AND MAINTENANCE.

H. Peter Jost and W. Bye.

HAL Technical Society Digest, vol. 3, July 1963, p. 28-35.

Discussion of the various applications of molybdenum-disulphide as a lubricant in the field of production engineering. Shown are the advantages of the use of molybdenum-disulphide as a method of overcoming difficult conditions of lubrication in the service life of an aircraft. The application of the correct grade

of molybdenum-disulphide, either in the form of a dry or semi-dry film, or in a suitable carrier, will improve lubrication in virtually every case. However, except for running-in, it may be uneconomical to use this material where normal lubricants are already proving quite satisfactory.

# 1963
# STAR ENTRIES

**N63-10194** Southwest Research Inst., San Antonio, Tex.
**RESEARCH ON HIGH-TEMPERATURE BEARINGS [Final] Technical Report [Mar. 10, 1960-Mar. 1962]**
R. D. Brown, R. A. Burton, and P. M. Ku Wright-Patterson AFB, Ohio, Flight Dynamics Lab., Aug. 1962 80 p 15 refs
(Contract AF 33(616)-7209)
(ASD-TR-61-705)

A description is presented of the evaluation work performed on oscillating bearings of both plain journal and self-aligning types. The bearing substrate materials included cermets LT-1B and LT-2, and alloys F-48 and René 41. Lubricants receiving extensive evaluation were a clad silver-palladium alloy, molybdenum disulfide used in cavities, and bonded molybdenum disulfide. Results include those from friction and wear evaluations, radial load capacity tests on plain journal bearings, and axial and radial load capacity tests on self-aligning bearings. Author

**N63-10787** Rock Island Arsenal Lab., Ill.
**WEAR AND CORROSION TENDENCIES OF MOLYBDENUM DISULFIDE CONTAINING GREASES Technical Report**
S. Fred Calhoun Aug. 15, 1962 23 p 19 refs
(RIA-62-2752) OTS: $0.75

The tendency of molybdenum disulfide to increase the wear of greases is shown by results of laboratory tests. The extreme pressure properties of greases were increased by the addition of the molybdenum disulfide. It also promotes rusting of ferrous metals when added to grease. Author

**N63-12405** Space Technology Labs., Inc., Redondo Beach, Calif.
**OGO SOLAR ARRAY DRIVE AND SHAFT SUPPORT BEARING TESTS**
J. C. Heindl and R. J. Belanger Sept. 20, 1962 82 p
(TR 2311-6026-RU000)

A series of tests were performed to provide design information on materials and lubricants for ball bearings to be used in the space environment. The loads, speeds, and modes of operation were chosen to be representative of those anticipated in the OGO Solar Array Drive and Shaft Support Bearings. Both R-4 size and 1-13/16-in ID bearings were tested at $10^{-7}$ mm of Hg and speeds of from 1 to 4 rpm for one month with instantaneous torques automatically recorded. The bearings were all 440C CRES alloy. The retainer materials tested included sintered bronze, 416 CRES, Delrin, DUROID 5813, and a phenolic. The lubricating coatings investigated were gold plating, molybdenum disulfide, and a vacuum deposited multilayer film, CBS Laboratories' #CDL5940. The results indicated the most satisfactory performance was obtained using gold-plated balls, races, and a gold-plated 416 CRES retainer, all burnished with $MoS_2$ in conformance with STL Process Specification PR1-1. Author

**N63-13326** Frankford Arsenal. Pitman-Dunn Labs., Philadelphia, Pa.
**COMPATIBILITY OF LUBRICANTS WITH MISSILE FUELS AND OXIDIZERS**
Kurt R. Fisch (ASD. Materials Central, Wright-Patterson AFB), Louise Peale, Joseph Messina, and Henry Gisser Repr. from ASLE Trans., v. 5, 1962 p 287-296 11 refs Presented at the Annual Meeting of the Amer. Soc. of Lubrication Engineers (ASLE), St. Louis, May 1962
(Rept. A62-13)

Various compounds were studied to determine their suitability as lubricants in the presence of fuels and oxidizers used in missile systems. The classes of compounds studied were the halogenated aliphatic and aromatic hydrocarbons, the silicon and perfluorocompounds, esters, ethers, and compounds containing nitrogen. The fuels and oxidizers included ethyl alcohol, hydrocarbon fuel, unsymmetrical dimethylhydrazine, diethylenetriamine, a mixture of the latter two, hydrogen peroxide, inhibited red fuming nitric acid, and liquid oxygen. The most promising compounds were studied for their extreme pressure, antiwear, volatility, and viscometric properties. Three compounds were found to be completely inert (unreactive and insoluble) with all the fuels and oxidizers. One was a liquid (perfluorotributylamine) and the other two were solids (polytetrafluoroethylene and tetrafluoroethylene-hexafluoropropylene copolymer). The perfluorotributylamine exhibited adequate lubrication properties except for excessive volatility. The preparation of higher homologs of this compound is expected to remedy this shortcoming. The polytetrafluoroethylene and the copolymer may find application as components of a grease-type lubricant. Author

**N63-13457** Lockheed Missiles and Space Co., Sunnyvale, Calif.
**LUBRICATION UNDER SPACE/VACUUM CONDITIONS Technical Report**
Francis J. Clauss Oct. 1962 69 p refs
(Contract AF 04(647)-787)

The effects of space environment on friction, wear, and the selection of lubricants and self-lubricating materials for spacecraft mechanisms are discussed, with special emphasis on the ultrahigh vacuum of space. Experimental studies have demonstrated the feasibility of using selected oils and greases to lubricate loaded ball bearings without replenishment for periods of over one year under the following conditions of operation: speeds of 8000 rpm, temperatures of 160° to 200° F, and vacuum of $10^{-8}$ torr. Over one-half year of successful operation has been achieved under similar operating conditions with self-lubricating retainers of reinforced Teflon, provided that the loads were light. Bonded films of molybdenum disulfide have given shorter lifetimes and poor reproducibility. Metal-to-metal slip-ring contacts introduce excessive electrical noise into circuits when operated in vacuum of $10^{-7}$ torr. The noise (as well as the friction and wear) can be markedly reduced by providing a small amount of oil vapor, sufficient to maintain a pressure on the order of $10^{-6}$ torr, or by incorporating molybdenum disulfide into the brush material. Author

**N63-14735** Convair, Fort Worth, Tex.
**MATERIALS—SOLID FILM LUBRICANTS—IRRADIATION AT FOUR AND ONE TEMPERATURE—EFFECTS OF [Report on Tests] Nov. 25, 1957 to Feb. 7, 1958**
J. H. Mc Kenna Feb. 28, 1958 16 p 1 ref
(Contracts AF 33(600)-32054 and AF 33(657)-7248)
(FGT-1880)

In order to determine the effects of nuclear radiation on Electrofilm #4396 solid film lubricant, test specimens, as received from the vendor, were exposed to four flux levels at ambient temperature in Materials Component Irradiation #6. Results of the tests showed a marked increase in wear-life of irradiated specimens. Significantly, this increase followed a positive slope from Flux I (lowest level) to Flux III, and then a negative slope to Flux IV (highest level). Concurring with nuclear studies over the past few years, the test data indicated that irradiation was responsible for polymerization of the resin binder in the lubricant film, promoting cross-linking of the polymer bond and thereby causing better film adhesion. At Flux III, this phenomenon theoretically reached the maximum permissible radiation level for this polymer. At Flux IV, excessive crosslinking probably caused embrittlement of the polymer, resulting in somewhat decreased adhesion and wear-life characteristics of the lubricant. Author

**N63-15272** General Plastics Corp. Bloomfield, N.J.
**PRODUCTION OF THIN POLYTETRAFLUOROETHYLENE RESIN (TEFLON) COATINGS BY ELECTRODEPOSITION METHODS Final Report, Mar. 19, 1962 to Mar. 19, 1963**
Robert W. Logan [1963] 76 p 33 refs
(Contract Now-62-0600-C)

An electrodeposition method of applying thin polytetrafluoroethylene resin ("Teflon") coatings has been developed which allows the application of crack-free films up to 0.001 in. thick in one coating operation. Polytetrafluoroethylene (TFE) coatings applied by this method are intended to supplement sprayed TFE coatings in lubricating, without the use of oils or greases, a wide variety of military equipment. Electrodeposited TFE coatings possess a very low coefficient of friction on steel, are smooth and free from blisters, cracks, coagulated particles and other surface defects, and exhibit adhesion (under simulated dry-lubricant conditions) comparable to sprayed TFE coatings. The electrodeposition process will allow the coating of parts or equipment that heretofore were difficult, if not impossible, to spray. In addition, due to the generally favorable edge in the economics of the electrodeposition process vs. the spray process, TFE may now be applied to parts which previously were not economically feasible to coat. The main limitation of the electrodeposition process is that only those metals which are anodically corrodible and which can withstand the 700° to 750° F sintering temperature can be coated. This eliminates aluminum, stainless steel, and zinc, among others. Author

**N63-15897** Rock Island Arsenal Lab., Ill.
**EFFECT OF CURE CONDITIONS ON WEAR LIFE AND CORROSION PROTECTION OF A RESIN-BONDED SOLID FILM LUBRICANT**
F. S. Meade and G. P. Murphy Mar. 26, 1963 21 p 9 refs
(RIA-63-959) OTS: $0.50

A resin-bonded solid-film lubricant was applied to grit blasted steel, zinc phosphatized steel, and preheated zinc phosphatized steel. The coating was then cured at temperatures from 200° F to 500° F for times ranging from 10 to 180 minutes. The effect of these cure conditions on wear life and corrosion protection was determined. The following information was obtained from this investigation: (1) Grit blasted steel is inferior to the other two substrates. (2) At cure temperatures above 300° F, the resin-bonded solid-film lubricant does not prevent the loss of water of hydration from the zinc phosphate coating and the resultant loss in corrosion protection. (3) No one set of cure conditions gives optimum wear life and corrosion protection. (4) Wear life increases with increasing cure time and temperature. (5) Corrosion protection increases with decreasing cure time and temperature. (6) Cure conditions depend on the application for which the resin-bonded solid-film lubricant is to be used. Author

**N63-17683** Mechanical Technology Inc., Latham, N.Y.
**INVESTIGATION OF COMPLEX BEARINGS AND/OR LUBRICATION SYSTEMS Second Quarterly Technical Progress Report, Aug. 1-Nov. 1, 1962**
P. Lewis, S. F. Murray, and M. B. Peterson Nov. 6, 1962 47 p 5 refs
(Contract AF 33(657)-8666)
(MTI-62TR34)

Research on complex bearing and/or lubrication systems for flight accessory equipment that operates at temperatures from −65° F to 1500° F, in high vacuum or in normal atmosphere, and while exposed to nuclear radiation, is summarized. The rolling element system was selected as the most promising for meeting the requirements of this program. The bearing materials will be a metallic for temperatures below 1000° F, and a ceramic or carbide above 1000° F. Stellite or René 41 below 1000° F, and titanium carbide or aluminum oxide above 1000° F. Solid lubricant powders were selected for lubrication use. Thus far, powders which form molybdates, tungstates, and silicates have been selected; these reaction films form low-shear-strength adherent films. The evaluations thus far have been made on films formed by an initial application of lubricant. It will be necessary to determine the life expectancy of these films and the supply requirements. A built-in solid lubricant circulating system is felt to provide the most versatile lubricant supply system. The most critical problem is that of getting the powder into suspension. Switching from one bearing system to the other is to be accomplished by means of an expanding spacer. N.E.A.

**N63-17684** Mechanical Technology, Inc., Latham, N.Y.
**INVESTIGATION OF COMPLEX BEARING AND/OR LUBRICATION SYSTEMS Third Quarterly Progress Report [Nov. 1, 1962-Feb. 4, 1963]**
P. Lewis, S. F. Murray and M. B. Peterson Feb. 12, 1963 45 p
(Contract AF 33(657)-8666)
(MTI-24(1-63); MTI-63TR5)

Research was conducted on the development of complex bearings and lubrication systems for flight accessory equipment that will operate at temperatures from −65° F to 1500° F, in high vacuum or normal atmosphere, and while exposed to nuclear radiation. The target specifications are for a self-contained bearing system that will operate at 30,000 rpm. Two types of materials were selected for bearing use: metals for below 100° F and ceramics for above 100° F. It appears that two separate solid lubricants will be required, one for the metal bearing and one for the ceramics bearing. For the low-temperature metal bearing, a carbon-graphite retainer looks like an interesting possibility in conjunction with molybdenum disulfide. But this system lacks protection from oxidation. In the high-temperature bearing, the complex oxides appear to be promising. The major problem in this system is to find a suitable retainer material which will provide any supplementary oxide desired and will still have suitable oxidation resistance. C.L.W.

**N63-17830** General Electric Co. Flight Propulsion Div., Cincinnati, Ohio
**LUBRICANT REQUIREMENTS FOR ADVANCED FLIGHT PROPULSION**
D. C. Berkey [1963] 12 p Presented at 1963 USAF Aerospace Fluids and Lubricants Conf., Session I San Antonio, Tex., Apr. 16–19

The lubricant requirements of present and future jet and rocket aircraft engines are summarized. While present needs are met with existing lubricants, future (Mach 2.5 to 3.5) engines will need fluids with improved thermal and oxidation stabilities, acceptable low-temperature viscosities, and higher spontaneous ignition temperatures. The need for a good supersonic transport engine lubricant and for a solid lubricant for extended operation above 1000° F is emphasized. D.E.R.

**N63-17866** Naval Air Experimental Station. Aeronautical Materials Lab., Philadelphia, Pa.
**THE EFFECT OF THE CHEMICAL COMPOSITION OF METALS IN SOLID LUBRICATION**
M. J. Devine, E. R. Lamson, and J. H. Bowen, Jr. [1963] 15 p 18 refs Presented at the 1963 USAF Aerospace Fluids and Lubricants Conf., Session V-B, San Antonio, Tex., Apr. 16–19

The relationship of alloy constituents and chemical composition of lubricating solids in the processes of lubrication have been explored to establish basic concepts. The lubrication characteristics displayed by metallic sulfides as a class of compounds for molybdenum metal, and the significance of metal composition for surfaces having sliding contact in bearings operating at 10,000 rpm and 750° F is described. Experimental results for a bonded solid-film lubricant under these conditions of speed and temperature provided 1100 hours of wear life. A description of a vacuum system designed to operate at pressures in the range of $1 \times 10^{-6}$ mm Hg, and at temperatures as high as 1000° F is shown, as well as results of studies conducted under the combined vacuum and temperature environment. Author

**N63-17867** Aeronautical Systems Div., Air Force Systems Command, Wright-Patterson AFB, Ohio
**SOLID FILM LUBRICANT DEVELOPMENT FOR AIR FORCE REQUIREMENTS**
B. D. Mc Connell [1963] 11 p 7 refs Presented at the 1963 USAF Aerospace Fluids and Lubricants Conf., Session V-B, San Antonio, Tex., Apr. 16–19

The requirements and capabilities of lubricants for use in aircraft, missiles, and other weapon systems are discussed. These requirements include operation at high temperatures in both oxidizing environments and vacuums ($10^{-6}$ torr). The crystal properties of solid lubricants, with concentration on single crystals of graphite, were studied along with the phase changes and reactions which take place in a ceramic-bonded solid-film lubricant at different temperatures. Different bonding techniques were also studied. Measurements of the cohesive energy between layers of mica and graphite were conducted; data indicated that there is a thirtyfold increase in the energy required to separate the layer in vacuum ($10^{-13}$torr) as in air. Helium, argon, and nitrogen were found to have no effect on the cohesive energy, but water vapor was found to cause separation of layers at a pressure of $10^{-1}$torr. The PbS-$B_2O_3$ lubricant was investigated, and the $B_2O_3$ was found to govern the frictional and lubricating behavior of this lubricant. The data gathered from the study of this lubricant will allow selection of materials having the specific properties needed to formulate superior high-temperature solid-film binders. Tests were conducted on ceramic adhesives, and the results indicate the possibility of obtaining formulations of high-temperature adhesives and lubricating pigments which may have potentiality as solid-film lubricants. C.L.W.

**N63-17868** Midwest Research Inst., Kansas City, Mo.
**FRICTION AND WEAR CHARACTERISTICS OF A CERAMIC-BONDED SOLID-LUBRICANT FILM**
M. T. Lavik and W. L. Clow [1963] 9 p 4 refs Presented at the 1963 USAF Aerospace Fluids and Lubricants Conf., Session V-B, San Antonio, Tex., Apr. 16–19

This paper summarizes friction and wear studies of the PbS:$MoS_2$:$B_2O_3$ lubricant system. A review of the film preparation and evaluation techniques used in the investigation is given. The wear-life and friction performance of the films in this system are discussed. In electron micrography of film surfaces, consideration is given surface films rubbed in air and surface films rubbed in a vacuum. Results of the film performance show that (1) the film wear-life is very good in air over a limited temperature range near 1000° F and friction coefficients remain below 0.20; (2) the films exhibit useful wear and friction properties over the temperature range 80° to 1000° F in both air and vacuum ($\sim 10^{-6}$ Torr). The wear-lives are proportional to $e^{-cT}$ and are approximately 300 percent longer in vacuum than in air. Film structure results show that (1) the films rubbed in air at 700° F exhibit much more severe and extensive wear areas than similar films rubbed in vacuum; (2) the wear patterns of film rubbed at 700° F in vacuum are composed of closely spaced rub marks in the film areas still intact; few areas of severe wear are noted; (3) films rubbed at 1250° F in vacuum exhibit diffuse rub marks and relatively large-scale plastic deformation. N.E.A.

**N63-19014** Westinghouse Electric Corp. Westinghouse Research Labs., Pittsburgh, Pa.
**LUBRICATION OF BEARINGS AND GEARS IN AEROSPACE ENVIRONMENTAL FACILITIES**
Paul H. Bowen Arnold Air Force Station, Tenn., Arnold Eng. Develop. Center, July 1963 134 p 11 refs
(Contract AF 40(600)-915)
(AEDC-TDR-63-166)

This report presents results of screening tests of plastics, powders, and composites, along with the use of new dry powders and composites, as dry lubricants in ball bearings and gears operating in an ultrahigh-vacuum environment. Conclusions are drawn with regard to concepts of dry lubrication, lubrication techniques, and desirable composite materials in adapting bearings and gears for use in handling equipment of environmental space chambers. Author

**N63-20587** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**GALLIUM-RICH FILMS AS BOUNDARY LUBRICANTS IN AIR AND IN VACUUM TO $10^{-9}$mm Hg**
D. H. Buckley and R. L. Johnson Repr. from ASLE Trans., v. 6, 1963 p 1–11 4 refs

The friction and wear characteristics of various materials coated with thin gallium-rich films were determined at temperatures to 1000° F in air and at room temperature in vacuum between $10^{-7}$ and $10^{-9}$ mm Hg. Evaporation rates of gallium were measured at $10^{-7}$ mm Hg and ambient temperatures to 1000° F. The friction and wear experiments were conducted with 3/16-inch-radius rider hemisphere sliding on a 2 1/2-inch-diameter disk at surface speeds of 28 to 4490 feet per minute and a load of 1000 gms. Utilizing a gallium-diffused film, boundary lubrication of 440-C stainless steel was obtained. The friction and wear obtained with the gallium-diffused films were lower in vacuum than in air. The use of relatively inert materials such as boron carbide and aluminum oxide as rider specimens reduced the corrosion problem normally encountered with gallium in all-metal systems. Gallium was not equally effective as a lubricant for all materials; it reduced friction and wear for several alloys (52100 and 440-C); other materials, including a nickel base alloy, were not effectively lubricated. Author

**N63-20798** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**WEAR AND FRICTION OF MECHANICAL CARBONS IN LIQUID OXYGEN AS INFLUENCED BY TRANSFER FILMS**
William F. Hady, Gordon P. Allen, and Robert L. Johnson Repr. from ASLE Trans. v. 6, 1963 p 201–208 10 refs
(NASA-RP-5)

Experimental wear and friction studies were conducted with a series of mechanical carbons sliding against metal surfaces in liquid oxygen (−298° F), at sliding velocities to 6500 fpm, and a load of 1000 gm. High-density graphitic carbons with a greater oxidation resistance and a greater capability of forming a transfer film gave the lowest wear and friction. Metals that form the most stable oxide films promote greater adherence of the graphite to the mating surface. Impregnated carbons must be selected with caution because frictional heating generated during sliding can initiate hazardous reactions between oxygen and certain unstable organic compounds. Author

**N63-21300** General Motors Corp., Bristol, Conn.
**RESEARCH AND DEVELOPMENT OF AIRFRAME BEARINGS FOR AEROSPACE VEHICLES [Final Report, May 1962–June 1963]**
R. J. Matt, J. B. Muratore, R. E. Murteza, and C. J. Zupkus Wright-Patterson AFB, Ohio, Flight Dyn. Lab., Sept. 1963 107 p 12 refs
(Contract AF 33(657)-8431)
(ASD-TDR-63-716)

The purpose of the program was to acquire the materials performance characteristics necessary to design control-surface bearings for future space reentry vehicles. The friction, wear, and limiting load capacity of candidate superalloy, cermet, and ceramic specimen materials, with and without lubricants, were studied at temperatures of from −100° F to 2500° F in air. Subsequent tests were run at temperatures of from −100° F to 1500° F in an ultrahigh vacuum ranging from $10^{-6}$ to $10^{-9}$ torr. Results indicated significant differences in performance

of the selected materials. None of the tested lubricants provided any significant improvement. The effect of ultrahigh vacuum substantially increased the coefficient of sliding friction and did not appear to increase the coefficient of rolling friction. High-temperature reentry-vehicle control-surface bearing materials appear feasible. Additional work is required to demonstrate the effects of thermal and mechanical shock, and variable duty cycle. Author

**N63-21409** McDonnell Aircraft Corp., St. Louis, Mo.
**EFFECTS OF ANTI-SEIZING COMPOUNDS AND LUBRICANTS ON HIGH TEMPERATURE ALLOYS AT ELEVATED TEMPERATURES Final Report**
[Oct. 30, 1961] 210 p
(Contract AF 33(657)-11215)
(A078)

The test was conducted in two phases. The first phase subjected seven different alloys to the effects of twenty-two different compounds at a temperature of 1000° F for ten hours. In the second phase, six of these alloys were subjected to twenty of the compounds at a temperature of 1800° F for ten hours. The results of the first phase of the test indicate that none of the compounds tested cause significant change in the microstructure of the alloys, observable at 250X, for temperatures up to 1000° F. At 1800° F, however, considerable corrosion was present. The type and degree of corrosion varied with the different compounds and alloys. From the results of this test, it could be assumed that any of the compounds tested would be satisfactory for use on these alloys at temperatures to 1000° F, but care should be used in selecting an alloy-compound combination for use in the higher temperature range. Author

# 1964
# IAA ENTRIES

**A64-10705**
INVESTIGATION OF BINDERS FOR SOLID LUBRICANTS AT ELEVATED TEMPERATURES.
Bernard C. Stupp and John W. Wright (Hohman Plating and Manufacturing Co., Dayton, Ohio).
(American Society of Lubrication Engineers, Annual Meeting, 18th, New York, N.Y., Apr. 30-May 2, 1963.)
Lubrication Engineering, vol. 19, Nov. 1963, p. 463-468; Discussion, p. 469; Author's Closure, p. 469.

Investigation of several materials as binders for solid lubricant materials having molybdenum disulfide and graphite as lubricating pigments. Binders investigated were silicates, borates, phosphates, and combinations of these materials with metal oxides. This investigation shows the results of wear life tests made on these binders to temperatures of 350C. Effect of temperature on wear life, coefficient of friction, film weight loss, film density, and chemical composition are shown for one composition having sodium phosphate as a binder.

**A64-11352**
WEAR CONSIDERATIONS IN DESIGN. II.
Charles Lipson (Michigan, University, Ann Arbor, Mich.).
Machine Design, vol. 35, Nov. 7, 1963, p. 177-185. 10 refs.

Consideration of surface film prevention of friction between two sliding surfaces. The coefficient of friction is seen to depend directly on the degree to which the surface film prevents asperity contact and on the strength of the junctures formed by the welding that does occur. Oxide and graphite carbon films are discussed, and the properties of extreme pressure, liquid, and solid lubricants are delineated. The nature of abrasion is briefly considered, and methods of abrasion control using rubber are outlined.

**A64-15648**
ADAPTATION OF A $MoS_2$ "IN SITU" PROCESS FOR LUBRICATING SPACECRAFT MECHANICAL COMPONENTS.
Charles E. Vest (NASA, Goddard Space Flight Center, Greenbelt, Md.).
IN: AIAA ANNUAL STRUCTURES AND MATERIALS CONFERENCE, FIFTH, PALM SPRINGS, CALIF., APRIL 1-3, 1964 (AIAA Publication CP-8).
New York, American Institute of Aeronautics and Astronautics, 1964, p. 120-125. 6 refs.

Evaluation of a $MoS_2$ "in situ" process for lubrication of spacecraft mechanical components. It is concluded that (1) the film thickness can be controlled within ± 35 micro inches; (2) the average coefficient of friction of this film is 0.05 or less and is comparable to or the same as $MoS_2$ powder and lower than bonded $MoS_2$ films; (3) the film can be easily and safely deposited onto a number of common spacecraft materials, including 2024 Al, 6061 Al, 7075 Al, 303SS, 316SS, 416SS, 440C SS, mild steel, M10 tool steel, and Circle "C" tool steel; (4) the film has a better wear life than sodium silicate bonded $MoS_2$, slightly better wear life than a burnished $MoS_2$ powder, and a somewhat poorer wear life than epoxy bonded $MoS_2$; and (5) the film follows the surface contour and fills up the smallest crack, lap, seam or indentation and therefore makes it possible to place a controlled amount of $MoS_2$ on hard to reach surfaces, such as outer races of miniature ball bearings.

**A64-19125**
MECHANISM OF LUBRICATION FOR SOLID CARBON MATERIALS IN VACUUM TO $10^{-9}$ MILLIMETER OF MERCURY.
Donald H. Buckley and Robert L. Johnson (NASA, Lewis Research Center, Cleveland, Ohio).
(American Society of Lubrication Engineers, Lubrication Conference, Rochester, N.Y., Oct. 15-17, 1963.)
ASLE Transactions, vol. 7, Jan. 1964, p. 91-100. 29 refs.

Determination in vacuum, at ambient pressures from 760 to $10^{-9}$ mm Hg, of the friction and wear characteristics of various carbon materials sliding on metals and aluminum oxide. The friction and wear experiments were conducted with a hemispherically tipped carbon rider, under a load of 1 kg, sliding on various disks rotating at a speed of 390 ft/min. The results of this investigation are stated to show that additional research on carbon in vacuum is warranted. Adsorbed surface films present on both carbons and metal, as well as the presence of oxide on metals, appreciably influenced the friction and wear obtained with carbons in vacuum. Some impregnants were beneficial in reducing friction and wear of carbon in vacuum, while others were not.

**A64-20633**
LONG-LIVED LUBRICATION FOR SPACECRAFT EQUIPMENT.
Francis J. Clauss (Lockheed Aircraft Corp., Lockheed Missiles and Space Co., Sunnyvale, Calif.).
Society of Automotive Engineers and American Society of Mechanical Engineers, Air Transport and Space Meeting, New York, N.Y., Apr. 27-30, 1964, Paper 871C. 14 p.
Members, $0.75; nonmembers, $1.00.
Research supported by USAF and Lockheed Missiles and Space Co.

Discussion of vacuum and radiation conditions in space and their influence on lubrication for spacecraft equipment. It is stated that, while many lubricants suffer a drastic loss in lifetime, as a result of these environments, experimental studies have demonstrated that certain oils and greases can lubricate lightly loaded ball bearings without replenishment for periods of 18 months to 2 years under the following conditions of operation: speeds of 8000 rpm, temperatures of 160 to 200°F, and vacuum of $10^{-8}$ torr. Selected oils and greases are also said to have lubricated satisfactorily at radiation doses of $10^7$ r in vacuum, which is more than twice the internal dose that would be accumulated in a period of 1 year in space. Experimental evaluations of molybdenum disulfide and special retainer materials are also discussed.

**A64-21052**
AROMATIC POLYIMIDE COMPOSITIONS FOR SOLID LUBRICATION.
M. J. Devine (Naval Air Engineering Center, Aeronautical Materials Laboratory, Philadelphia, Pa.) and A. E. Kroll (Du Pont de Nemours and Co., Physics Dept., Du Pont Experimental Station, Wilmington, Del.).
(American Society of Lubrication Engineers, Annual Meeting, 19th, Chicago, Ill., May 26-28, 1964.)
Lubrication Engineering, vol. 20, June 1964, p. 225-230. 6 refs.

Discussion of the mechanical and lubricant properties of an aromatic polyimide plastic. Data on such properties are given and compared with those of other materials. The discussed results of studies conducted at temperatures ranging from 77 to 700°F show that aromatic polyimide compositions are exceptionally heat stable, retaining good mechanical and electrical properties up to 700°F. Solid sections of filled aromatic polyimide plastic are shown effective as a self-lubricating component of a ball bearing assembly at temperatures up to 700°F and speeds of 10,000 rpm. The presented test results demonstrate that lubrication can be provided by the polyimide composition functioning as the retainer. Bearing design considerations for solid lubrication extend the self-lubricating polymer to include usage as a land material. The importance of dimensions for components fabricated from the polyimide is noted.

**A64-21245**
MECHANO-CHEMICAL FACTORS IN $MoS_2$-FILM LUBRICATION.
G. Salomon (T.N.O., Central Laboratory, Delft, Netherlands), A. W. J. De Gee, and J. H. Zaat (T.N.O., Metal Research Institute, Delft, Netherlands).
(Conference on Fundamental Mechanisms of Solid Friction, Midwest Research Institute, Kansas City, Mo., Sept. 16-18, 1963.)
Wear, vol. 7, Jan.-Feb. 1964, p. 87-101. 35 refs.
Research sponsored by Alpha Molykote Corporation, Molykote Produktionsgesellschaft m.b.H., and Molykote S.A.R.L.

Study of the friction properties and the well-reproducible endurance limits of $MoS_2$-lubricant films, prepared from the dry powder. Special consideration is given to: (1) automation of the rubbing-in process, (2) the control of temperature and atmosphere, and (3) photographic recording of the friction surface. The influence of physical factors is found to be similar to that known already for resin-coated $MoS_2$ films. Life expectancy is shortened by certain factors including: (1) instantaneously scoring pairs of metals as substrates, and (2) mechano-chemical reaction with water vapor and with oxygen. In a neutral atmosphere, the life of the lubricant film is long.

**A64-21246**
AN EVALUATION OF THE ROLE OF VAPOR LUBRICATION MECHANISMS IN $MoS_2$.
A. J. Haltner (General Electric Co., Research Laboratory, Schenectady, N.Y.).
(Conference on Fundamental Mechanisms of Solid Friction, Midwest Research Institute, Kansas City, Mo., Sept. 16-18, 1963.)
Wear, vol. 7, Jan.-Feb. 1964, p. 102-117. 16 refs.

Study of the sliding behavior of $MoS_2$ in room air, in controlled atmospheres, and in vacuum at pressures as low as $10^{-9}$ torr. The results confirm the occurrence of friction transients under a number of experimental conditions. However, evidence indicates that these transient effects are not involved in the sliding mechanism. It is concluded that, unlike graphite, $MoS_2$ does not depend on a vapor lubrication mechanism.

**A64-21247**
A STUDY OF MECHANISMS OF GRAPHITE FRICTION AND WEAR.
P. J. Bryant, P. L. Gutshall, and L. H. Taylor (Midwest Research Institute, Kansas City, Mo.).
(Conference of Fundamental Mechanisms of Solid Friction, Midwest Research Institute, Kansas City, Mo., Sept. 16-18, 1963.)
Wear, vol. 7, Jan.-Feb. 1964, p. 118-126. 15 refs.
Contract No. AF 33(657)-10122.

Discussion of a basic research program conducted to determine fundamental phenomena involved in lubrication by graphite and other lamellar solids. Lamellar cleavage experiments in known environments of air, ultrahigh vacuum, water vapor, and oxygen are reported. A theoretical calculation of the interlamellar binding energy of the ideal graphite lattice is described. A stress-etch process is reported for graphite, in dry oxygen, water vapor, and air environments which significantly lowers the cleavage energy and provides a basis for understanding lubrication phenomena. A general hypothesis of lamellar solid lubrication is thereby proposed on the basis of interlamellar binding forces. A correlation of this general hypothesis is made with experimental results for the lamellar materials graphite, molybdenite, pyrophyllite, muscovite, margarite, talc, and phlogopite.

**A64-21761**
LUBRICATING PROPERTIES OF LEAD FILMS ON COPPER.
Yuko Tsuya and Riitsu Takagi (Government Mechanical Laboratory, Tokyo, Japan).
Wear, vol. 7, Mar.-Apr. 1964, p. 131-143; Discussion, p. 175-177. 11 refs.

Study of the frictional behavior between a lead film, 0.1-130μ thick, deposited on an annealed copper surface and an electropolished similar copper surface at a sliding speed of 0.005 cm/sec under a pressure of 0.4-100 kg/cm$^2$. The friction coefficient μ, which is generally higher for a thicker film, decreases at a given film thickness under increasing pressure, at first steeply and then gradually beyond 5 kg/cm$^2$. The smallest friction-coefficient (0.4) obtained at the highest pressure is, however, about ten times the value (shear strength of lead)/(hardness of substrate copper) predicted by the Bowden-Tabor theory. The area of real contact is actually determined by the hardness of copper substrate, at least for thinner films, and the shearing occurs within the lead film; however, the increase of the area actually sheared off through the growth of adhesive masses that occurs on application of the frictional force makes μ considerably larger than that predicted by the theory.

**A64-22749**
FRICTION VARIATION OF PTFE AND $MoS_2$ DURING THERMAL VACUUM EXPOSURE.
W. D. Craig, Jr. (Grumman Aircraft Engineering Corp., Mechanical Systems Section, Bethpage, N.Y.).
(American Society of Lubrication Engineers, Annual Meeting, Chicago, Ill., May 26-28, 1964.)
Lubrication Engineering, vol. 20, July 1964, p. 273-276; Discussion, A. J. Haltner (General Electric Co., Research Laboratory, Schenectady, N.Y.), p. 276-277; Author's Closure, p. 277. 21 refs.
Contract No. NAS 5-814.

Experimental study of the starting-friction characteristics of thin-film fused polytetrafluoroethylene (PTFE) and $MoS_2$-graphite-sodium silicate coatings to determine their suitability for space applications. Studies were made at temperatures from -130°F to +200°F in vacuum between $10^{-7}$ and $10^{-8}$ torr, with bearing pressures of about 10 psi. Exposure to vacuum for 5 months did not result in coating degradation. The friction of run-in bearings at room temperature was found to be approximately the same in vacuum as in air. The friction of the $MoS_2$-graphite-sodium silicate was only slightly changed by temperature, while that for PTFE varied inversely with temperature, showing a decrease in rate of change below -100°F and above 150°F.

**A64-22851**
ON THE SLIDING FRICTION OF A LIGHT ALLOY ON POLYTETRAFLUOROETHYLENE (PTFE) PURE OR CHARGED AT RAPIDLY VARIABLE SPEEDS (0 TO 100/KM/HR) [SUR LE FROTTEMENT DE GLISSEMENT D'UN ALLIAGE LEGER SUR DU POLYTETRAFLUOROETHYLENE (PTFE) PUR OU CHARGE A DES VITESSES RAPIDEMENT VARIABLES (0 A 100 KM/H)].
Pierre Nadal, Michel Lavault, Jean Blouet, and Robert Courtel (Laboratoire de l'I.S.M.C.M., Saint-Ouen; Laboratoire de Sud-Aviation, Courbevoie; Centre National de la Recherche Scientifique, Centre Technique d'Analyse des Surfaces de Frottement, Bellevue, Seine-et-Oise, France).
Académie des Sciences (Paris), Comptes Rendus, vol. 258, no. 12, Mar. 23, 1964, p. 3182-3184. In French.

Experimental determination of the friction coefficient of a light alloy (AG 5) sliding at different pressures against PTFE charged with graphite, used in the state of bondable thin sheets. A tribometer of modern design has enabled investigation of a wide range of linear

speeds and the corresponding development of the friction. It is concluded that the addition of charges, such as micronized graphite, to PTFE, enables expansion of the limits of its lubricating power at high speeds.

**A64-24390**
LUBRICATION OF SMALL MOTOR BEARINGS FOR UNATTENDED SERVICE IN AUTOMATIC EQUIPMENT.
George H. Kitchen (Bell Telephone Laboratories, Inc., Murray Hill, N.J.).
(American Society of Lubrication Engineers, Annual Meeting, 19th, Chicago, Ill., May 26-28, 1964.)
Lubrication Engineering, vol. 20, Aug. 1964, p. 311-315; Discussion, Charles E. Vest (NASA, Goddard Space Flight Center, Greenbelt, Md.), p. 315; Author's Closure, p. 315.

Experimental study to determine the most effective lubricant for the lubrication of the bearings of small electric motors found in automatic, unattended, electromechanical equipment. The objects of the study are to attain maximum wear life and minimization of sliding friction between balls and races. It is found that a high concentration of molybdenum disulfide in a mineral oil-lithium grease provides both maximum life and minimum sliding friction.

# 1964
# STAR ENTRIES

**N64-11237*** National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
**HIGH SPEED VACUUM PERFORMANCE OF GOLD PLATED MINIATURE BALL BEARINGS WITH VARIOUS RETAINER MATERIALS AND CONFIGURATIONS**
Harold E. Evans and Thomas W. Flatley Washington, NASA Dec. 1963 21 p refs
(NASA TN D-2101) OTS: $0.75

Metallic film lubrication of ball bearings is a possible answer to the evaporation, radiation resistance, and contamination problems associated with conventional lubricants in satellite applications. The first phase of the program which evolved was directed toward finding an acceptable retainer material and configuration. Bearings were tested in small 10,000 rpm motors in a special multiport oil-free vacuum system which is described. Two retainer types—fully machined retainers of S-Inconel and silver plated Circle C—proved outstanding and capable of providing about 1000-hours life in conjunction with gold plated balls and races.
Author

**N64-11992*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**EVAPORATION RATES FOR VARIOUS ORGANIC LIQUID AND SOLID LUBRICANTS IN VACUUM TO $10^{-8}$ MILLIMETER OF MERCURY AT 55° TO 1100° F**
Donald H. Buckley and Robert L. Johnson Washington, NASA Dec. 1963 28 p refs
(NASA TN D-2081) OTS: $0.75

The fluids examined were polyphenyl ethers, silicones, and polyalkylene glycols; the solids included fluorocarbon telomers, polytetrafluoroethylene (PTFE), polychlorotrifluoroethylene (PCFE), and two phthalocyanines (metal free and copper). Some greases were also examined. Variations in molecular weight influenced evaporation rate markedly as indicated by the Langmuir equation. With five polyalkylene glycol fluids having different compositions but approximately the same molecular weight (1000), no essential difference in evaporation rates could be measured from 50° to 450° F. A similar dependence of evaporation rate on molecular weight was noted for the solids—telomers PTFE, and PCFE.
Author

**N64-12079** Ampex Corp., Redwood City, Calif.
**THE EFFECT OF EXTERNAL PRESSURIZATION ON SELF-ACTING FOIL BEARINGS**
M. Wildmann and A. Wright Oct. 1963 34 p refs
(Contract Nonr-3815(00))
(RR 63-6; AD-424200)

The effects of introducing a small amount of lubricant under pressure into a self-acting foil bearing film are investigated. Foil shape and pressure distribution under the foil are obtained by combining the equilibrium equation with the Reynolds equation and solving the resulting equation. The results show that the effect of even small external pressurization in a self-acting foil bearing is very important.
Author

**N64-13253** McDonnell Aircraft Corp., St. Louis, Mo.
**EVALUATION OF DRY FILM LUBRICANTS ON ALUMINUM AND MAGNESIUM [Final Report]**
M. S. Tucker 10 Dec. 1963 44 p
(Contract AF 33(657)-11215)
(A262; AD-425071)

Vendors' literature has recommended the application of dry film lubricants to various aluminum and magnesium alloys. In order to evaluate these recommendations, combinations of several dry film lubricants applied to representative aluminum and magnesium alloys with various surface preparation procedures were tested. Of the combinations tested, the optimum combination of surface pretreatment and dry film lubricant in the case of 7075-T6 aluminum alloy was found to be Electrofilm 5396 lubricant applied to a hard coated surface. When testing HK31A magnesium alloy, the optimum combination was that of Electrofilm 5396 applied to a surface pretreated with a Dow 17 Type I coating, followed by Everlube 620 lubricant applied to the same pretreated surface.
Author

**N64-15236*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**FRICTION OF METALS, LUBRICATING COATINGS, AND CARBONS IN LIQUID NITROGEN AND HYDROGEN**
Edmond E. Bisson *In its* Advanced Bearing Technol. 1964 p 289-307 refs (See N64-15226 07-01) GPO: $1.75

Data from friction and wear studies on various material combinations in liquid nitrogen and in liquid hydrogen are discussed. Friction and wear data were obtained with three common metals in liquid nitrogen. These data show that, with types 304 austenitic stainless steel sliding on 304, the wear of the rider specimen is fairly high. With two other steels, type 52100 conventional bearing steel sliding on 52100 and type 440C stainless steel sliding on 440C, wear was lower than with type 304 on 304. The wear and friction properties of austenitic steel with various surface coatings in liquid nitrogen were investigated, and the results are reported. Wear and friction investigations were also conducted with solid bodies of various plastics and of impregnated carbons in liquid nitrogen and liquid hydrogen.
C.L.W.

**N64-15237*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**EXTREME-TEMPERATURE BEARINGS**
William J. Anderson *In its* Advanced Bearing Technol. 1964 p 309-370 refs (See N64-15226 07-01) GPO: $1.75

Approaches are discussed of bearing-operation problems in the areas from −65° F down to temperatures approximating

those of liquid helium, and from temperatures of 400° F up to an absolute maximum of 3,000° F. Results obtained by various investigators in the field are examined. The discussion concerning low-temperature bearings included friction and wear experiments, high-speed bearing experiments, and the general design philosophy of bearings for use in cryogenic applications. In the high-temperature region, applications included those at low rotative speeds or oscillating motion and a very high load. The discussion covers materials, lubricants, and bearing designs—three major problems that are encountered in operating rolling contact bearings at high temperatures.
C.L.W.

**N64-15240*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**LUBRICATION OF BEARINGS WITH LIQUID METALS**
William J. Anderson *In its* Advanced Bearing Technol. 1964 p 469–496 refs (See N64-15226 07-01) GPO: $1.75

Fluids primarily considered for use as cycle working fluids are mercury and the alkali metals—rubidium, potassium, sodium, and lithium. The properties of liquid metals that can affect the performance of bearings are their low viscosity and their corrosivity. The alkali metals reduce most metal oxides, and the high mass density of mercury tends to promote erosion because of high particle inertia. The discussion includes types of bearings, bearing experiments, properties of bearing materials, properties of liquid metals, and operating problems. C.L.W.

**N64-17565*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**MECHANISM OF LUBRICATION FOR SOLID CARBON MATERIALS IN VACUUM TO $10^{-9}$ MILLIMETER OF MERCURY**
Donald H. Buckley and Robert L. Johnson Repr. from ASLE Trans., v. 7, 1964 p 91–100 refs Presented at the Lubrication Conf., Rochester, N.Y., 15–17 Oct. 1963
(NASA RP-146)

The friction and wear characteristics of various carbon materials sliding on metals and aluminum oxide were determined in vacuum at ambient pressures from 760 to $10^{-9}$ mm Hg. The friction and wear experiments were conducted with a hemispherically tipped carbon rider, under a load of 1,000 sliding on various disks rotating at a speed of 390 fpm. The results of this investigation show that additional research on carbon in vacuum is warranted. Adsorbed surface films present on both carbons and metal, as well as the presence of oxide on metals, appreciably influenced the friction and wear obtained with carbons in vacuum. Author

**N64-17653** Rocketdyne, Canoga Park, Calif.
**RESEARCH IN THE FIELD OF LIQUID-METAL-LUBRICATED BEARINGS, PART I**
J. Hall and R. Spies Wright-Patterson AFB, Ohio, Res. and Technol. Div. Feb. 1964 77 p refs
(Contract AF 33(657)-10553)
(R-5438, Pt.1; RTD-TDR-63-4289, Pt.1; AD-432451)

A new general purpose test rig (GPTR) was constructed and checked out. The ability to measure bearing operating attitude was developed. The system was calibrated successfully. This new test rig which can support test loads in excess of 100 pounds, has nearly twice the capability of the previous test rig. Antiwhirl journal bearings of the hybrid type were designed and fabricated. Checkout series in the GPTR using water lubricant were performed preparatory to testing with potassium. The design of a special test rig (system simulation test rig) to be utilized in studying rotordynamic characteristics of typical space power systems with antiwhirl bearings was completed. This rig incorporates three potassium-lubricated test bearings, i.e., two journal bearings and one thrust bearing. Author

**N64-17752*** National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
**ROLLING ELEMENT SLIP RINGS FOR VACUUM APPLICATION**
Edward J. Devine Washington, NASA, Apr. 1964 17 p refs (NASA TN D-2261) OTS: $0.50

Electrical slip rings employing rolling contact elements (balls and raceways) were tested in a hard vacuum environment. Low-noise operation was achieved at speeds up to 5,000 rpm. Slip rings lubricated with $MoS_2$ operated with lower noise and had a longer life than slip rings employing solid metal film lubrication. Noise generated by rolling slip rings is more severe in air than in a hard vacuum. A technique was developed that operated satisfactorily in air for a time sufficient for preflight testing. A method of replenishing $MoS_2$ lubrication on the slip rings was devised. The final configuration operated in a vacuum of $2 \times 10^{-9}$ torr at 2,000 rpm for over 100 million revolutions at a noise level of 0.002 ohm rms. Author

**N64-18068** Mechanical Technology Inc., Latham, N.Y.
**BEARING MATERIALS FOR PROCESS FLUID LUBRICANTS**
**Progress Report No. 3**
M. B. Peterson and F. F. Ling, Oct. 1963 29 p refs
(Contract Nonr-3731(00) FBM)
(MTI-63TR41; AD-420961)

An investigation was conducted into the nature of surface damage that resulted from high-speed sliding contacts. The first portion of the program consisted of an analytical temperature solution for transient case for two bodies in sliding contact. In exploratory studies of high-speed, short-time contacts, the following results were obtained: (1) Gold, bronze, and chrome plate gave the least surface damage of the materials tested that could be considered for high-temperature applications. (2) Considerable difference was noted in the damage that resulted in short-time contact at high speed in contrast to that which would be expected from longer sliding times. In certain cases the damage was more severe (tool steel) and, with others, less severe (titanium carbide, 440C stainless). Author

**N64-18091** Joint Publications Research Service, Washington, D.C.
**HIGH-TEMPERATURE LUBRICATION AND INORGANIC SOLID SUBSTANCES**
Ch'en Shao-li and Ou-yang Chin-lin *In* "Transl. on Communist China's Sci. and Tech., no. 76" 26 Mar. 1964 p 19–25 refs Transl. into ENGLISH from K'o Hsueh T'ung Pao (Peking), no. 12, 1963 p 59–61
(JPRS-23893; OTS-64-21906) OTS: $1.00

A brief report is presented of investigations of the friction-temperature characteristics of various types of inorganic solid powders. The substances included high-melting-point metal oxides, sulfides, salts (inorganic and organic), silicates, graphite, and carbon black. The test results indicate that the selection of multimixture inorganic solid substances is one hopeful means of maintaining low friction and high resistance against wear for high-temperature solid lubricants of wide temperature ranges. P.V.E.

**N64-19014** Texas A. and M. Research Foundation, College Station
**KINEMATICAL RELATIONS AMONG RADAR-OBSERVED WATER CONCENTRATIONS, VERTICAL MOTIONS, AND LIQUID-WATER DROP-SIZE SPECTRA IN CONVECTIVE CLOUDS**
R. C. Runnels (M.S. Thesis), R. A. Clark, and V. E. Moyer 31 Dec. 1963 77 p refs
(NSF Grant 13834)
(Sci. Rept. 63-31T)

A simple convection cell represents convective cloud motions for analysis using radar-measured parameters. The relationships existing between the atmospheric fields of the wind and liquid-water concentration are determined by considering a one-dimensional (vertical) continuity equation for water substance. Atmospheric values of parameters in the continuity equation are determined from radar reflectivity measurements. Empirical equations relating a particular parameter to radar reflectivities are used. The generation term accounting for water phase change in the continuity equation is significant for the center of a convective cloud. A linear variation of the generation term with height is shown. Generation decreases with increasing height. Dropsize distributions inferred from median volume drop diameters give greater liquid-water concentrations than concentrations determined from radar reflectivity data. The mean vertical speeds of convective clouds can be determined to some extent from cloud parameters measured by a weather radar. Author

**N64-19364*** National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
**ADAPTATION OF A $MoS_2$ "IN SITU" PROCESS FOR LUBRICATING SPACECRAFT MECHANICAL COMPONENTS**
Charles E. Vest *In* AIAA 5th Ann. Structures and Mater. Conf. 1964 p 120-125 refs (See N64-19359 12-01) AIAA: $7.50 members, $15.00 nonmembers

This "in situ" process consists of surface activation treatment—electrodeposition of an $MoO_3$ complex ion onto the substrate surface, and conversion of this film to $MoS_2$ in an atmosphere of $H_2S$ gas at 400 psig pressure and 195° C, for an exposure period of 4 to 8 hours. From the work performed and the test results, it is concluded that this process is adaptable to space components. It is also concluded that: (1) the film thickness can be controlled within $\pm 35\,\mu$ inches; (2) the average coefficient of friction of this film is 0.05 or less, and is comparable to or the same as $MoS_2$ powder and lower than bonded $MoS_2$ films; (3) the film can be easily and safely deposited onto a number of common spacecraft materials; (4) the film has a better wear life than sodium silicate bonded $MoS_2$, slightly better wear life than a burnished $MoS_2$ powder, and a somewhat poorer wear life than epoxy bonded $MoS_2$; and (5) the film follows the surface contour and fills up the smallest crack, lap, seam, or indentation. P.V.E.

**N64-19596*** Midwest Research Inst., Kansas City, Mo.
**DEVELOPMENT OF SOLID FILM LUBRICANTS FOR USE IN SPACE ENVIRONMENTS**
Vern Hopkins and Donald Gaddis [1963] 24 p Presented at USAF Aerospace Fluids and Lubricants Conf., San Antonio, Tex., Apr. 1963
(NASA Contract NAS8-1540)
(NASA CR-53835) OTS: $2.60 ph

This research program is concerned with the development of inorganic solid film lubricants suitable for service in space environments. Friction coefficients are given for many potential lubricants subjected to a light load and temperatures from 80° to 400° F in both a normal air atmosphere and in a vacuum of $10^{-6}$ torr. The main criterion for judging the performance of a potential lubricant film was the friction coefficient, which must be less than that obtained for a 0.001-in.-thick film of gold. The following lubricant films exhibited lower overall friction coefficients than a 0.001-in.-thick gold film: $MoS_2$ + graphite + bismuth–sodium silicate; $MoS_2$ + graphite + gold–sodium silicate; $MoS_2$ + graphite + molybdenum–sodium silicate; $MoS_2$ + graphite–sodium silicate; and $MoS_2$ + graphite–sodium phosphate. Author

**N64-20047** General Dynamics/Fort Worth, Tex.
**MATERIALS – SOLID FILM LUBRICANTS – IRRADIATION BY THE GTR AND $Co^{60}$ SOURCES – EFFECTS ON WEAR-LIFE**
J. W. Head 15 Apr. 1964 7 p
(Contract AF 33(657)-11214)
(FTDM-3006; AD-438132)

Three solid-film lubricants were tested to determine wear-life characteristics after irradiation at ambient chamber temperature in the Ground Test Reactor (GTR). No significant effects were produced. Testing was not done for effects of cobalt 60. A.W.

**N64-20049** General Dynamics/Fort Worth, Tex.
**MATERIALS – CERAMIC BONDED SOLID FILM LUBRICANTS – EFFECTS OF IRRADIATION AND HIGH TEMPERATURE ON**
J. W. Head 15 Apr. 1964 8 p
(Contract AF 33(657)-11214)
(FTDM-3053; AD-438137)

Film A (molybdenum disulfide + lead sulfide + boric oxide) would operate with friction coefficients of 0.4 or less only at 1000° F and so was tested only at that temperature both before and after irradiation. There was no significant effect due to exposure to reactor radiation. Film B (calcium fluoride + oxide frit) was unable to carry the prescribed load at any temperature, and so was deleted from the program. No significant effects were noted from wear life determinations conducted at 600° F and 1200° F on Film C (molybdenum disulfide + graphite + sodium silicate). A.W.

**N64-20051** General Dynamics/Fort Worth, Tex.
**WING PIVOT – DRY FILM LUBRICANT EVALUATION**
J. D. Reynolds 15 Apr. 1964 9 p
(Contract AF 33(657)-11214)
(FTDM-3113; AD-437609)

One of the most promising methods of lubricating the wing pivot on the F-111 is to use a solid film lubricant. A test was performed on seven commercial resin-bonded solid film lubricants to determine the three most promising methods. Testing was performed on the Hohman A-6 test machine. The three lubricants showing the most satisfactory wear life under test conditions were Alpha Molykote X-106, Surf-Kote M1284, and Almasol X-38. A.W.

**N64-21147** Ampex Corp., Redwood City, Calif.
**AN INVESTIGATION OF SELF-ACTING FOIL BEARINGS**
Joseph T. Ma Mar. 1964 41 p refs
(Contract Nonr-3815(00))
(RR-64-3; AD-600657)

Experimental results on the interior and exit region film-thickness measurements of self-acting foil bearings are presented and discussed. These measurements were made with capacitive sensors and conductive foils. The measured and predicted values agree very well within the range of nondimensional parameters—$h_o/R$, from $10^{-4}$ to $10^{-3}$; and, $T/\mu U$, from $10^5$ to $10^6$. Empirical expressions for predicting the constant and minimum film thickness applicable beyond these ranges are also presented. They are valid within the range of $h_o/R$ from $5(10)^{-5}$ to $10^{-2}$ and $T/\mu U$ from $10^4$ to $10^6$. The validity of a growing sinusoidal film thickness in the exit region first predicted by Gross is evidenced from the photographs. The measured wavelengths checked with Barlow's calculated values within 6%. For a constant relative velocity, the effect of increasing tension is to decrease the film thickness, whereas for a constant tension, the effect of increasing speed is to increase the film thickness. The effect of gas compressibility becomes

important for high relative velocity, and the effect of surface roughness greatly influences either the predicted or measured values for thin film thickness. Author

**N64-21268*** National Aeronautics and Space Administration. Goddard Space Flight Center, Greenbelt, Md.
**HIGH SPEED VACUUM PERFORMANCE OF MINIATURE BALL BEARINGS LUBRICATED WITH COMBINATIONS OF BARIUM, GOLD, AND SILVER FILMS**
Thomas W. Flatley Washington, NASA, Jun. 1964 14 p refs
(NASA-TN-D-2304) OTS: $0.50

A retainer study that involved bearings with gold-plated balls and raceways resulted in the selection of fully machined retainers of "S"-Inconel and of silver-plated Circle "C." Bearings with these retainer types and six ball and race plating combinations of barium, gold, and silver were studied. They were run in pairs in small induction motors in a vacuum environment, with nominal test conditions of 10,000 rpm, no external loading, and an oil-free ambient pressure in the $10^{-7}$ torr range. Testing revealed only one bearing configuration worthy of further study, that involving gold-plated balls, silver-plated raceways, and the fully machined silver-plated Circle "C" retainer. In direct contrast the combination of silver-plated balls and gold-plated raceways gave consistently poor performance. Bearing lifetimes achieved with the other configurations, all involving barium plating, in general fell between these extremes. Author

**N64-21563** General Dynamics/Fort Worth, Tex. Nuclear Aerospace Research Facility
**EFFECTS OF REACTOR RADIATION ON CERAMIC-BONDED SOLID-FILM LUBRICANTS**
F. A. Haley and R. H. McDaniel 30 Aug. 1963 28 p refs
(Contract AF 33(657)-7201)
(NHRF-63-6T; MR-N-302; AD-417167)

Two solid-film lubricant formulations (PbS + $MoS_2$ + $B_2O_3$ and $MoS_2$ + graphite + sodium silicate) have been exposed to reactor radiation and tested for wear life on a Hohman A-6 wear tester. Substrate material was Inconel X, rub shoes were of Rex AAA, load per shoe was 110 lb, and sliding speed was 128 fpm. Several test temperatures up to 1,200° F were employed. It was concluded that a gamma dose of $1.47 \times 10^{11}$ ergs/gm(C) and a neutron flux of $2.85 \times 10^{16}$ n/cm$^2$ (E > 2.9 Mev) had no significant effect on the wear life of these films. Author

**N64-22595** McDonnell Aircraft Corp., St. Louis, Mo.
**INVESTIGATION OF THE EFFECT OF DRY FILM LUBRICANTS ON CORROSION RESISTANCE Final Report**
10 Jun. 1964 92 p
(Contract AF 33(657)-11215)
(A753; AD-441131)

The results of this investigation indicate that both Electrofilm 2306 and Everlube 620 lubricants used on alodined 2024 and 7075 aluminum decreased the corrosion resistance of these alloys with this surface treatment by a considerable degree. The corrosion resistance of cadmium-plated 4340 steel was adversely affected by the use of Molykote X-106 lubricant. In all of the other cases tested, the lubricants did not decrease the corrosion resistance of the alloys to any great degree, and there were several instances where the lubricants acted to increase the corrosion resistance of the alloys to which they were applied. Author

**N64-22596** McDonnell Aircraft Corp., St. Louis, Mo. Structures Lab.
**EFFECT OF CADMIUM PLATE ON DRY FILM LUBRICANT WEAR LIFE Final Report**
Billie L. Thrasher 10 Jun. 1964 15 p
(Contract AF 33(657)-11215)
(A754; AD-441132)

This test was conducted to gather data concerning the effects of cadmium plate substrate on the wear life and corrosion resistance of dry-film lubricant coated bearings. Cadmium-plated, as well as unplated, steel test cups were used. The wear life of these cups was determined, using the MacMillan lubricant tester with an 80-rpm rotary motion and a 630-lb line-contact load. The corrosion resistance was investigated by first subjecting both plated and unplated test cups to a 4-hr wear test on the MacMillan tester, then to a 24-hr 20%-salt-spray exposure. This cycle was repeated until the coefficient of kinetic friction reached 0.2 on the wear-test portion of the cycle. The cadmium plate substrate decreased the average wear life of the lubricated surface by approximately 40%. Considerable corrosion was observed on both plated and unplated test cups after the first 24-hr salt-spray exposure. Author

**N64-22597** McDonnell Aircraft Corp., St. Louis, Mo.
**EFFECTS OF MOLYBDENUM DISULFIDE ON 19-9DL AND 321 STAINLESS STEELS AT 800° F**
10 Jun. 1964 13 p
(Contract AF 33(657)-11215)
(A755; AD-441133)

Tests were performed to determine the extent of attack by molybdenum disulfide coated on 19-9DL and type 321 stainless steel when exposed to temperatures up to 800° F and on A286 stainless steel when exposed to temperatures of 700° F and 1,000° F. No evidence of attack by molybdenum disulfide on any of the materials examined was observed metallographically. Author

**N64-23443** Air Force Systems Command, Wright-Patterson AFB, Ohio Foreign Technology Div.
***INVESTIGATION OF INORGANIC SALTS FOR THE PURPOSE OF USING THEM AS HIGH-TEMPERATURE LUBRICANTS***
M. M. Fialko and A. I. Dintses 7 Jan. 1964 10 p refs Transl. into ENGLISH from Khim. i Tekhnol. Topliv i Masel (Moscow), no. 10, 1963 p 22-26
(FTD-TT-63-1152/1+2; AD-430146)

An evaluation of antiwear and corrosion properties was the main object testing. The antiwear test was performed on a four-ball apparatus; the balls were made of silicon-molybdenum steel and had a 12.7-mm diam. The corrosion test was performed in a quartz test tube placed in a thermostat. The salt was placed in the test tube, and after its fusion the plates of the metal to be tested were inserted. Purified air was then blown through the fusion product. The corrosion was determined by the change in the weight of the plates. A.L.B.

**N64-26414*** National Aeronautics and Space Administration. Lewis Research Center, Cleveland, Ohio
**FUSED FLUORIDE COATINGS AS SOLID LUBRICANTS IN LIQUID SODIUM, HYDROGEN, VACUUM, AND AIR**
Harold E. Sliney, Thomas N. Strom, and Gordon P. Allen Washington, NASA, Aug. 1964 19 p refs
(NASA-TN-D-2348) OTS: $0.50

Fused coatings of $CaF_2$-$BaF_2$ mixtures were effective solid film lubricants for nickel-chromium alloys submerged in liquid sodium at 1,000° F and sliding at a velocity of 2,000 ft/min. Under these conditions, the coatings were not damaged after 2 hours of sodium exposure. Coatings of LiF and $CaF_2$-LiF mixtures lubricated effectively in sodium, but LiF was slowly dissolved and could not be considered for prolonged exposure. These coatings also showed lubricating potential in hydrogen, vacuum, and air. Author

**N64-27310*** Midwest Research Inst., Kansas City, Mo.
**RESEARCH ON BEARING LUBRICANTS FOR USE IN HIGH VACUUM Annual Summary Report, 23 Apr. 1963–22 May 1964**
Vern Hopkins, D. H. Gaddis, R. D. Hubbell, and F. W. Holm 5 May 1964 49 p refs
(Contract NAS8-1540; MRI Proj. 2492-E)
(NASA-CR-58039) OTS: $4.60

The wear life of a potassium silicate binder material was increased by the addition of sodium fluoride. A solid lubricant film composed of $MoS_2$, graphite, gold, and potassium silicate modified with sodium fluoride exhibited friction characteristics similar to those of MLF-5 and longer wear life (in air) than that of MLF-5. A description of six newly designed and fabricated wear-life testers is presented. MLF-5 exhibited friction coefficients as low as 0.04 at room temperature, in air, and at loads to 150,000 psi. An ultrahigh-vacuum apparatus was built and attained an ultimate pressure of $1.6 \times 10^{-13}$ torr. The preliminary design of a multistation vacuum friction apparatus is presented and discussed. Author

**N64-27311*** Pratt and Whitney Aircraft, West Palm Beach, Fla. Florida Research and Development Center
**RESEARCH AND DEVELOPMENT OF MATERIALS FOR USE AS LUBRICANTS IN A LIQUID HYDROGEN ENVIRONMENT Summary Report**
W. C. Keathley and E. W. Dwyer 18 Jun. 1964 89 p refs
(Contract NAS8-11537)
(NASA-CR-56947; PWA-FR-986) OTS: $8.10

A program was conducted to evaluate materials that can be used as lubricants in antifriction bearings operating in a liquid hydrogen environment at DN values from $2 \times 10^6$ to $4 \times 10^6$ mm-rpm. Even though no tests were conducted in a nuclear radiation field, consideration was given to such an environment in the selection of some of the candidate materials. The program described resulted in the discovery of a material that provides a significant increase in the possible bearing life when operating under the above conditions. Author

**N64-27900*** Midwest Research Inst., Kansas City Mo.
**RESEARCH ON BEARING LUBRICANTS FOR USE IN HIGH VACUUM Annual Summary Report, 23 Mar. 1962.–22 Apr. 1963**
Vern Hopkins and D. H. Gaddis 30 Aug. 1963 47 p refs
(Contract NAS8-1540; MRI Proj. no. 2492-E)
(NASA-CR-58204) OTS: $4.60 ph

Binder development studies were performed to develop better binders for solid lubricant films during the past year. Potassium silicate was selected as a basic binder. Preliminary results show that the wearlife of this binder material may be increased by additives such as sodium phosphate, potassium phosphate, sodium borate, or sodium fluoride. A search for additional lubricants or lubricant film components was conducted. Nine potential materials were selected for formulation and evaluation. A gear apparatus and pellet apparatus were designed, built, and used to investigate solid lubricant film wear life in air at room temperature. Wear characteristics of MLF-5($MoS_2$ + graphate + gold-sodium silicate) obtained in the early runs with the pellet apparatus are presented graphically. MLF-5 and other solid lubricant films were applied to a number of parts and components. A number of modifications that were made on the vacuum friction apparatus to improve its overall operating efficiency are described. Author

**N64-29801** General Dynamics/Fort Worth, Tex. Nuclear Aerospace Research Facility
**EFFECTS OF REACTOR RADIATION ON A CERAMIC-BONDED, A RESIN-BONDED, AND A METAL-MATRIX-BONDED SOLID-FILM LUBRICANT**
R. H. Mc Daniel 31 Mar. 1964 26 p refs
(Contract AF 33(657)-7201)
(NARF-63-IIT; MR-N-306; AD-603442)

Three solid-film lubricant formulations—PbS + $MoS_2$ + $B_2O_3$, GD/FW Dynalube, and Almasol SFD-560—have been exposed to reactor radiation and tested for wear life on a Hohman A-6 wear tester. Rub shoes were of Rex AAA steel; load per shoe was 110 lb; and sliding speed was 128 ft/min. Substrate materials were T-1 tool steel for GD/FW Dynalube and Timken standard test races (T-54148-3-233) for the other two lubricants. Several test temperatures up to 1,150° F were employed. The solid-film lubricant specimens received an average radiation exposure of $1.7 \times 10^{11}$ ergs/gm(C) of gammas and $3.7 \times 10^{16}$ n/cm$^2$ (E > 2.9 Mev) of neutrons. Significant decreases in wear life occurred at 80° and 900° F for Dynalube, and at 900° F for SFD-560; PbS + $MoS_2$ + $B_2O_3$ showed no change; and SFD-560 improved markedly at 80° F. Author

**N64-31310** Rock Island Arsenal Lab., Ill.
**SOLID FILM LUBRICANT SUBSTRATES**
G. P. Murphy and F. S. Meade 6 Feb. 1964 18 p refs
(RIA-64-1377; AD-602718) OTS: $0.50

A comparison of the wear life and corrosion protective ability of a recently developed solid-film lubricant (RIA Compound 9A) and two commercial solid-film lubricants was made. The substrates to which the solid-film lubricants were applied were: (1) grit blasted steel; (2) zinc phosphatized grit-blasted steel; (3) zinc phosphatized cadmium-plated steel; and (4) sulfuric acid anodized water-sealed aluminum. Author

**N64-32151** Thompson Ramo Wooldridge, Inc., Cleveland, Ohio Materials Processing Dept.
**HIGH TEMPERATURE EXTRUSION LUBRICANTS Final Technical Documentary Report, 1 Jul. 1962–15 Jun. 1964**
Robert C. Haverstraw Wright-Patterson AFB, Ohio, AF Mater. Lab., Jul. 1964 155 p refs
(Contract AF 33(657)-9141)
(ML-TDR-64-256; AD-606243)

Numerous experimental lubricant materials were initially evaluated by three laboratory screening tests: (1) A "lubricity" test was devised to measure the lubricating characteristics under conditions simulating those found in extrusion. A total of 265 compounds and mixtures were evaluated by this test. (2) A "reactivity" test determined the relative degree of surface reaction between billet materials and candidate lubricants. Both 4340 steel and molybdenum–0.5% titanium were tested at their respective extrusion temperatures with approximately 50 candidate lubricants each. (3) An "insulation" test measured comparative thermal insulation characteristics for all candidate lubricants that exhibited superior results in the lubricity test. More than 100 extrusion trials each were conducted with 4340 steel and molybdenum–0.5% titanium billets. Objectives of these trials were threefold: establishment of confidence levels for the laboratory tests, secondary screening of the experimental lubricants found to be superior by the laboratory tests, and complete evaluation of the final remaining experimental candidate lubricants. Author

# Subject Index



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